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DEVELOPMENT OF ENGINEERING METHOD FOR CALCULATION OF EJECTED AND RECIRCULATED AIR FLOW RATES DURING RELOAD OF BULK MATERIALS

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Abstract. Reload of bulk materials in various industries and agriculture are accompanied by significant dust emissions. The flow of bulk materials in its fall carries air (air ejection). The study of the flow of ejected air is a complex multidisciplinary task. The maintenance costs of local exhaust ventilation systems are directly proportional to the flow rate of the ejected air. Consumption of the ejected air can be reduced by: reducing the speed of the falling bulk material flow; increase of aerodynamic drag when ejected air moves; organization of air circulation-recirculation.

The aim of the article is to develop engineering methods of calculation of aspiration systems and shelters on the basis of previously obtained results of theoretical and experimental studies of the laws of ejected and recirculated air flow.

The results and conclusions are as follows.

The technique of engineering calculation of volumes of the aspirated air during reload of dry not heated materials with natural circulation, carried out by means of the combined use of the cylindrical bypass chamber and the perforated trough is developed. Experimental and numerical studies have shown that the proposed method has sufficient accuracy.

Recommendations for the design of the developed aspiration shelter for more efficient operation with lower operating costs are proposed. The economic effect is to reduce energy intensity and the cost of cleaning dust emissions.

The values are proposed for the recirculation coefficients for the calculation of the aspiration system using the bypass chamber and the combined use of the bypass chamber and the perforated trough.

The method of calculation of the ejected air flow rate in telescopic loaders is developed.

The high energy intensity of telescopic aspiration-technological units (ATU) of reloading stations is caused by the ejection ability of gravity flows of bulk material, pumping a large amount of air into the aspiration shelters, which significantly increases the required performance of aspiration systems. Power of ATU can be significantly reduced by the use of coaxial telescopic loading troughs and corrugated impervious wall surrounding the trough and sealing the top and bottom of the cover, adjacent to the troughs.

The analytical flow rates estimation of air, moving inside the cavity of the "trough- bypass

chamber", can be carried out by linearization of the dynamics and inter-component interaction equations with the subsequent solution of transcendent equations in the Maple universal mathematical environment.

Numerical studies have shown that the main parameter for reducing the transit flow of ejected air and increasing the volume of recirculated air is the degree of sealing of the upper cover. For example, if the total area of the shelter leaks is reduced from 0.14 m2 to 0.02 m2, the flow of transit air will be reduced three times, and the recirculated air will be increased by 2.5 times. The total productivity of the local suction from the lower shelter in this case has decreased by 1.68 times.

1 INTRODUCTION

Overloading of bulk materials in various industries and agriculture is accompanied by significant dust emissions [1-3]. The flow of particles of bulk materials in its fall carries away the air (air is ejected). Reducing the flow of ejected air allows to reduce the cost of dust collection and to design effective systems of local exhaust ventilation [4,5]. To reduce the flow rate of the ejected air by reducing the rate of fall of the flow of bulk material; increasing of aerodynamic resistance during the movement of ejected air; organization of air circulation - recirculation.

The purpose of the article is to develop on the basis of previously obtained results of theoretical and experimental studies of the laws of recirculation air flow, organized in the system “loading channel - bypass chamber” of the engineering methodology for calculating aspiration installations and shelters.

2 METHOD OF CALCULATING THE VOLUME OF AIR REMOVED FROM THE ASPIRATION SHELTER

Using a dynamic approach to determine the amount of ejected air, described in the monograph [4], as well as the data obtained in the experiments [6-9], an engineering method for calculating the amount of exhaust air, which allows to take into account the flow of ejected air and the influence of the design features of the shelter on amount of aspirated air and recirculated air flow was developed.

The basis of this technique is the calculated dependencies of the amount of ejected air, one of the main parameters of which is the aerodynamic resistance of the equipment: "top shelter - overload channel - bottom shelter" [5].

The initial data for the calculation are as follows:

1. Characteristics of the material being overloaded: particle size distribution, material density $\rho_м$, material consumption $G_м$.

2. Characteristics of the overload unit: layout of the unit with heights of the fall of the bulk material, type of aspiration shelter, cross-sectional area of the loading trough $F_ж$, loose area of the shelters.

The calculation of the volume of aspirated air is carried out in the following sequence.

1. The flow rate of the material falling along the trough at the entrance to the shelter $\upsilon_к$ is determined by calculating the speed of movement of the bulk material at each straight section of the loading channel:

a) for a vertical section

$$\upsilon_k = \sqrt{\upsilon_н^2 + 2gh},$$

b) for the inclined section

$$\upsilon_k = \sqrt{(\upsilon_н \sin a)^2 + 2gh(1 - 0.5\mathrm{ctg}a)}.$$

The speed in the trough shown in Figure 2.1 will be determined as follows:

a) the speed at the beginning of the trough

$$\upsilon_н = \sqrt{2gh_1},\ g = 9.81 m/s^2.$$

b) speed at the end of the section

$$\upsilon_к = \sqrt{\upsilon_н^2 + 2gh_2}.$$

2. The value of the volume concentration of particles in the trough, m^3/m^3:

$$\beta = 2G_м / \left(\rho_м F_ж (1+n)\upsilon_к\right),$$

where $n = \upsilon_н/\upsilon_к$ - the ratio of the velocity of falling of particles of bulk material at the beginning and end of the trough;

3. The average particle diameter of the bulk material, mm:

$$d = \sum_{i=1}^{9} m_i d_i,$$

where m_i - percentage of particles with a diameter d_i by weight.

For the value $d \le 14.6\sqrt{\beta}$ taken as calculated the average diameter should be taken $d = 14.6\sqrt{\beta}$.

4. The sum of coefficients of local resistances shelters and trough aspiration system

$$\sum\zeta = \zeta_{ву} + \zeta_ж + \zeta_{ну},$$

where $\zeta_{ну}$ - coefficient of local resistance of bottom shelter; $\zeta_ж$ - coefficient of local resistance of trough (for vertical trough $\zeta_ж = 1.5$; $\alpha = 90^\circ$); $\zeta_{ву}$ - coefficient of local resistance of top shelter.

For shelters with a rigid internal partition, the value $\zeta_{ну}$ depends on the ratio of the cross-sectional areas of the trough and the partition $F_ж/F_п$ and the ratio of the heights of the partition and the shelter $H_п/H_у$. The values for shelters are presented in table. 1. Without internal partition relies $\zeta_{ну} = 0$.

The value of coefficient of local resistance of the top shelter $\zeta_{ву}$ is calculated by formula:

$$\zeta_{ву} = 2.4\left(F_ж / f_н\right)^2,$$

where $f_н$ - area of leakage of top shelter, m^2.

5. The drag coefficient is determined by the formula:

$$\psi = 1.8\exp\left[-1.8\sqrt{\beta \cdot 10^3}/d\right].$$

Table 1: Value $\zeta_{ну}$ for shelters

$F_{ж}/F_{п}$	$H_{п}/H_{у}$				
	0.1	0.2	0.3	0.4	0.5
1.0	193	44.5	17.8	8.12	4.02
0.8	124	28.5	11.4	6.19	2.57
0.6	69.5	16.0	6.41	2.92	1.45
0.4	30.9	7.12	2.84	1.3	0.64
0.2	7.72	1.78	0.71	0.32	0.16
0.1	1.93	0.45	0.18	0.08	0.04

6. Value of the Butakov-Neykov number

$$\mathrm{Bu} = 1500\psi G_{м} v_{к} / \left(d \rho_{м} F_{ж} g \Sigma\zeta \right).$$

According to this formula, the number Bu is calculated for vertical troughs and for troughs with a predominance of vertical sections.

7. The value of the Euler criterion

$$\mathrm{Eu} = P_{у} \Big/ \Sigma\zeta \frac{v_{к}^{2}}{2} \rho_{в} , \tag{1}$$

where $P_{у}$ - depression in the bottom shelter, ρ - density of the exhaust air.

It is necessary to add to the vacuum in the shelter the amount of pressure $P_{об}$ generated by the working bodies of this equipment when aspirating technological equipment with ventilation capacity (roller and hammer crushers, disintegrators). In this case, the expression (1) takes the following form

$$\mathrm{Eu} = \ 2(P_{у} + P_{об}) \ / \rho_{в} \cdot V_{к}^{2} \cdot \Sigma\zeta \ ..$$

8. With known numbers Bu and Eu the slip coefficient of the components with a uniformly accelerated flow of bulk material is determined by the formula:

$$\varphi = \sqrt{\mathrm{Eu} + \mathrm{Bu}\left[|1-\varphi|^{3} - |n-\varphi|^{3} \right] / 3} . \tag{2}$$

Equation (2) is solved by the method of successive approximations, with the following initial approximation

$$\varphi_{1} = 0.5\left(0.5(1+n) + \sqrt{\mathrm{Eu}} \right). \tag{3}$$

If $\varphi_{1} < n$, then the value φ is determined from the quadratic equation, which follows from the expression (3):

$$\varphi = \sqrt{\left(b/(2a)^{2} \right) + c/a} - b/(2a) ,$$

where

$$a = 1 - \mathrm{Bu}(1-n) , \ b = (1-n)^{2} \ \mathrm{Bu} , \ c = \mathrm{Eu} + \mathrm{Bu}\left(1-n^{3}\right)/3 .$$

9. Air flow that enters in the bottom shelter by trough, m^3/s:

$$Q_{ж} = \varphi \cdot \upsilon_{к} \cdot F_{ж} \cdot (1-\beta)^2 .$$

10. Air flow which comes through leakages in the bottom shelter, m^3/s:

$$Q_{н} = 0.65 F_{н} \sqrt{2P_{у} / \rho} \, ,)$$

where $F_{н}$ - area of leakage of bottom shelter

11. Transit air flow, m^3/s:

$$Q_{т} = \kappa_{р} \cdot Q_{ж} , \tag{4}$$

where $\kappa_{р}$ - recirculation coefficient.

Transit air flow $Q_{т}$ shows how much air flows from the receiving part of the shelter to the aspirated part from which is removed in consequence. Transit flow depends on the amount of air entering the receiving part of the shelter along the trough. The value of the recirculation coefficient according to (4) is equal to the ratio of the transit and ejected (incoming through the trough) air

$$\kappa_{р} = Q_{т} / Q_{ж} .$$

It is also possible to determine the amount of recycled air

$$Q_{р} = Q_{ж} - Q_{т} .$$

Determination the value of the transit air flow is quite difficult. To simplify the calculation, it is proposed to use the values of the recirculation coefficient on the basis of the experimental values obtained performed during simulation and with bulk material overload with only a bypass chamber; $\kappa_{р} = 0.2 - 0.35$ - for the presence of a bypass chamber and perforation. These values of the recirculation coefficient were obtained for the optimal values of the cross-sectional area of the bypass chamber. According to experimental studies, the optimal ratio of the diameter of the bypass channel to the diameter of the loading pipe is 2-2.5.

For the perforation in the hydraulic path of system "top shelter - overload channel - bottom shelter" value $\zeta_{перф}$ is added to the sum coefficient of local resistance $\sum\zeta$.

12. Suction air consumption:

$$Q_{а} = Q_{т} + Q_{н}$$

The obtained values of air flow rates allows to make the hydraulic calculation of the air ducts of the aspiration system.

3 GENERAL RECOMMENDATIONS FOR THE DESIGNING ASPIRATION SYSTEM

The use of the aspiration system at the enterprises for the production of building materials, the metallurgical industry, the mining industry and the agro-industrial complex requires the solution of the following tasks.

1. The choice of a rational design of the aspiration shelter of the dusting place.

2. Calculation of the volumes of suction air required to prevent dust from escaping from the shelter.

3. Perform hydraulic calculation of air ducts.

4. Selection of a dust collector for cleaning aspirated air.

For conveyor overloads it is recommended to use the shelter design developed in this work the use of which will reduce the dust emission rate by reducing the amount of ejected air since a significant part of the air is recycled, and this in turn will reduce the loss of valuable material removed by suction.

It is recommended to use the developed shelter in the production of dry building materials (crushed stone, expanded clay), in metallurgical production (in case of pellet transshipment), and in the agricultural industry (in case of transshipment of grain materials).

Reducing the energy consumption for the operation of the aspiration system is achieved by using combined bypass and increasing the aerodynamic resistance of the receiving chamber.

The optimal ratio of the diameter of the bypass chamber $D_б$ to the diameter of the trough $D_ж$ for the implementation of effective air recirculation is a value of 2-2.5. When $D_б/D_ж > 2.5$ the speed of the upward recirculated air flow is reduced, which can lead to the settling of dust on the walls of the bypass chamber and its subsequent overgrowing and this in turn will adversely affect air recirculation. For smaller numbers $D_б/D_ж < 2$ in spite of the high air velocity its hydraulic resistance in the bypass chamber will be higher than with values of 2-2.5.

For optimal implementation of the process of closed air circulation, as mentioned earlier, it is necessary to have resistance between the inlet section into the bypass chamber and the aspiration funnel. With a high bypass chamber resistance most of the air will go to the aspirated chamber and then be removed which will reduce the bypass efficiency.

Also, the presence of seal curtain on the top shelter of the aspiration system is necessary. Their presence will reduce the inflow of atmospheric air which will lead to a decrease in the volume of ejected air which will ensure the presence of additional vacuum in the top shelter and eliminate dislodging of dusty circulating air through the leakage of the top shelter.

Perforation must be applied to the trough walls in its upper part. Perforation of the bottom of the trough in the area of overpressure can lead to the formation of an air curtain when the ejected air escapes from the holes. This kind of curtain will resist the upward flow of air during its transit flow. If during the movement of the bulk material in the loading chute, the ejection pressure will decrease due to the release of air through the perforations, the air curtain in the lower part will not occur, as in the case of the telescopic chute (Figure 1).

By perforating the upper part of the trough there are certain advantages, some of which have been confirmed experimentally:

- increases the vacuum zone in the cavity of the bypass chamber, since the falling bulk material creates a vacuum inside the trough and the circulating air rushes in through the perforations;
- at real overloads of the bulk material, the pressure along the length of the chute increases and reaches high values at the entrance to the lower shelter and if there is a perforation in the upper part of the increase will not occur, this is due to the fact that the falling material will partially push the air through the perforation, and due to the low air pressure inside the trough the formation of an air curtain will be excluded.

The presence of a vertical partition or internal walls limiting the receiving chamber of the lower cover allows reducing the dusting out of the dusty air into the working area of the room and also plays the role of the main resistance between the aspiration funnel and the bypass chamber.

4 CALCULATION METHOD OF VOLUME OF ASPIRATION OF OVERLOADING OF BULK MATERIAL AT TELESCOPIC STATIONS

The most common conveyor overloading of dusting materials with ordinary closed troughs is characterized by the fact that gravitational flows of particles during a fall create ejection jets of dusty air that enter shelters of the fall site (loading points of the lower conveyors or feeders, bunkers, crushers, screens and other process equipment).

To avoid knocking out the dusty air from these shelters into the surrounding atmosphere, not only is the maximum possible compaction of these shelters, but also air suction to create a vacuum in the cavities of not only the lower shelters, but also other shelters aerodynamically associated with aspirated shelters. The required amount of aspirated air Q_a (aspiration volume) for the simplest case of overload from the conveyor to the conveyor is determined by the sum of costs $Q_{н}$ and $Q_{ж}$, where $Q_{н}$ is the flow of air entering the shelter through leakages, depends on the area of leakage ($F_{н}$, m^2) and the amount of vacuum maintained in the shelter ($P_{у}$, Pa) to prevent the expiration of dusty air.

$$Q_{н} = \mu F_{н} \sqrt{2P_{у} / \rho_{о}} \quad ,$$

where $\mu = 1/\sqrt{\zeta}$ - the coefficient of consumption associated with the coefficient of local resistance of leakiness (for small holes $\zeta = 2.4$ and then $\mu = 0.65$); $\rho_{о}$ - ambient air density often taken to be 1,2 kg/m^3.

It is much more difficult to determine the amount of air flow $Q_{ж}$ through the trough, often referred to as the flow rate of the ejected air. In general, the air flow rate moving through the trough depends not only on the depression in the bottom shelter ($P_{у}$), but also on the ejection head ($P_{э}$, Pa) created by the aerodynamic force of the particles falling in the chute, and also on the magnitude of the thermal head ($P_{э}$, Pa) arising from the heat exchange of falling heated particles and air. In the one-dimensional approximation:

$$Q_{ж} = \mu F_{ж} \sqrt{2(P_{у} + P_{э} + P_{т}) / \rho} \quad ,$$

where ρ - air density in the trough, кг/м^3; $\mu = 1/\sqrt{\sum \zeta}$ - coefficient of discharge associated with the amount of coefficient of local resistance of trough, depending on the geometry of its elements. The calculation of the ejected air in the trough of the loading telescopic stations is considerably complicated. The loading stations of small volumetric capacity (up to 250 m^3 / h), such as the JETPACK TZS 500, as well as telescopic loaders of considerable capacity (up to 1500 m^3 / h) of the PU-700 type, used in marine terminals, consist of loading troughs with variable loading height which are two coaxial tubes. The cavity of the inner tube, along which the feed material moves, is aerodynamically connected with the cavity of a limited impermeable outer wall and inner permeable wall. This circumstance contributes to the organization of recirculation of the ejected air, which is quantitatively different from the ejection of air in the trough with an impenetrable wall.

4.1 Method of calculating the flow of ejected air in telescopic loaders

This method is based on the linearized equations of the dynamics of the ejected and recirculated air obtained in [5] (Fig. 1) with one ring of air recycling in the permeable chute with conventional (scheme a) and combined bypass (scheme b), i.e. with air recycling through two circulation rings, when the air ejected through the central channel is separated in the lower part of the telescopic trough and enters the bypass chamber (internal recycling).

Transit air flow at the exit of the chute is divided in turn into two parts, part of the air rises up through the bypass chamber 4 to the upper shelter, and the remaining part with the flow rate Q_g flows through the sealing aprons into the aspirated chamber from where the aspiration pipe is removed. The overall performance of the nozzles is determined by the obvious amount: $Q_a = Q_n + Q_g$, where Q_n is the flow rate of air entering through the leakiness of the outer sealing aprons due to the depression P_y created by the fan of the aspiration system.

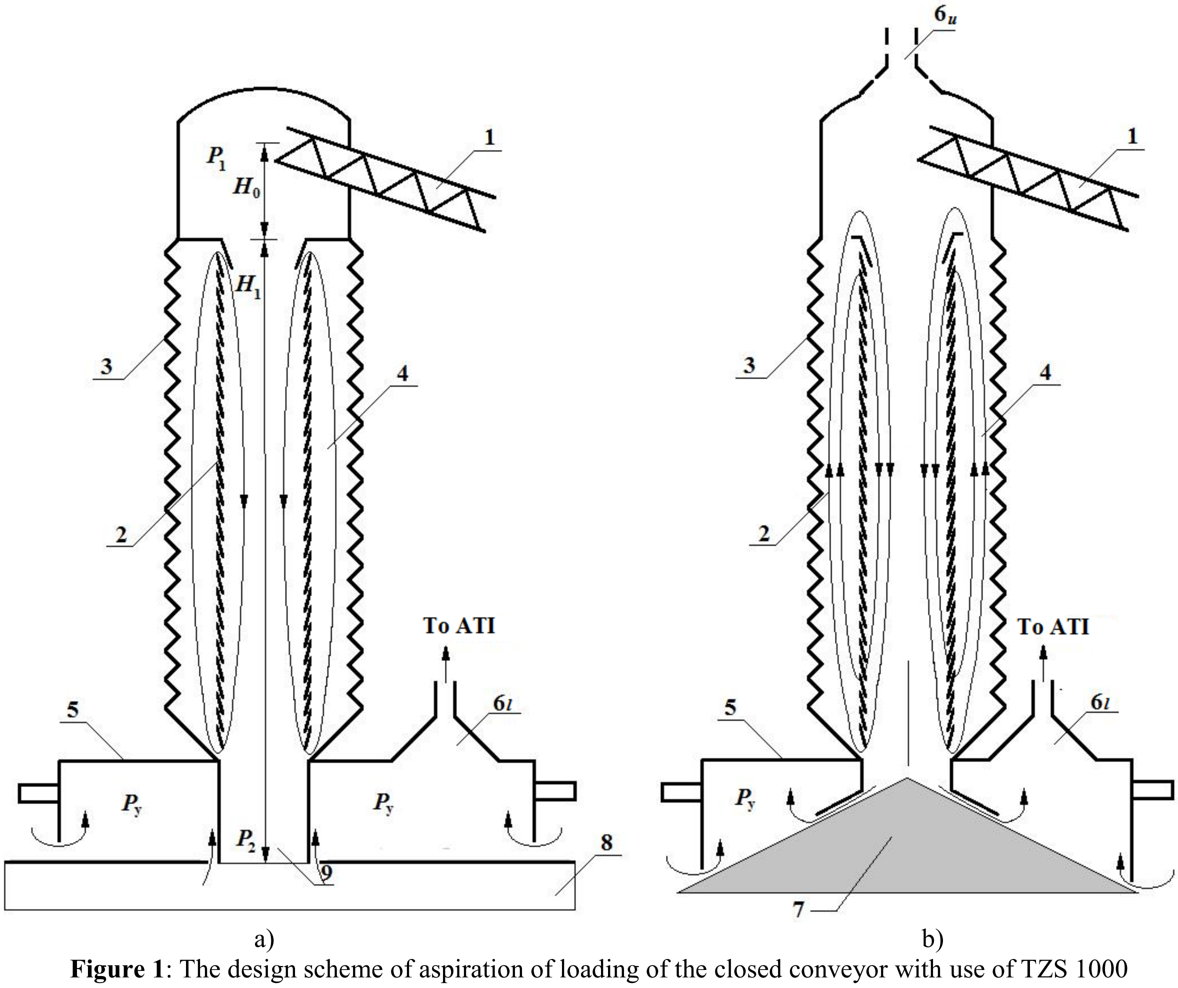

Figure 1: The design scheme of aspiration of loading of the closed conveyor with use of TZS 1000 JETRAPACK: 1 - loading auger; 2 - telescopic tube (trough); 3 - corrugated outer impermeable pipe; 4 - bypass chamber with closed (scheme a) upper and lower bottoms and with open (scheme b) bottoms; 5 - aspiration shelter; 6_l - lower suction nozzle; 6_u - upper suction nozzle; 7 - stack of granular overloaded material; 8 - closed container; 9 - loading neck

It is necessary to determine the main component of the balance equation Q_g.

Initial data for calculation: G_m - mass flow rate of the material being loaded, kg / s,; H_1 - trough height, m; d_1 - diameter of the upper base of the telescopic tube section, m; d_2 - diameter of the lower ($d_2 < d_1$) base of this section, m; diameter of the outer sleeve of the trough D_n, m; verage clearance between adjacent gutter sections $z_c = (d_1 - d_2)/2$, m; $D_1 = (d_1 + d_2)/2$ - nominal diameter of the trough, m; $S_g = \pi D_1^2/4$ - - the cross-sectional area of the trough, m ^{2}; $f_{zo} = \pi D_1 z_c$ - conditional area of the living section of one gap, m^2; N_g - number of sections in a telescopic tube, pcs; $S_z = f_{zo} N_g$ - total area of all gaps, m^2; $S_\omega = \pi(D_n^2 - D_1^2)/4$ - bypass chamber area, m^2; $r = S_\omega / S_g$; $e_s = S_z / S_g$ - relative degree of permeability; ζ_o - coefficient of local resistance of holes clearance; ζ_m - coefficient of local resistance of openings leakages of the outer wall of the aspiration shelter; $E = e_s / \sqrt{\zeta_o}$ - degree of flow of air through the refraction holes of the trough; S_{nw} - area of leakages of top shelter, m^2; S_{nk} - the area of leakages of bottom shelter (receiving chamber), m^2; $\zeta_{nw} = 2.4\left(S_g / S_{nw}\right)^2$ - coefficient of local resistance to air inlet through leakage of the top shelter; $\zeta_{nk} = 2.4\left(S_g / S_{nk}\right)^2$ - coefficient of local resistance to air inlet through leakage of the lower cover; P_y - depression in the aspirating bottom shelter chamber, Pa; F_a - the area of leakages of the outer wall of the aspirated chamber; ψ_o - coefficient of drag of a single particle; ρ_m - particle density, kg / m^3; ρ_g - air density in the trough, kg / m^3; ρ_w - density of external air, kg / m^3; d_e - equivalent particle diameter, mm; H_0 - height of falling of particles, m; $v_n = \sqrt{2gH_0}$ - particle velocity at the entrance to the trough, m / s; $v_k = \sqrt{2g(H_1 + H_0)}$ - particles velocity at the outlet of the trough, m / s; $n = v_n / v_k$ the ratio of the velocity of falling of particles; $p_y = 2P_y / (\rho g v_k^2)$ - dimensionless depression in the aspirated chamber of the bottom shelter.

After the formation of the initial data, the calculation is performed in the following sequence.

1. The volume concentration of falling particles at the end of the telescopic trough is determined: $\beta_k = G_m / \left(v_k \rho_m S_g\right)$; and in the middle of this trough: $\beta_y = 2G_m / \left(v_k (1+n) \rho_m S_g\right)$.

2. Calculating the average drag coefficient of falling particles by the formula: $\psi = \psi_0 \exp\left[-56{,}92\sqrt{\beta_y} / d_e\right]$.

3. Determining the ejection parameter: $\mathrm{Le} = \psi \beta_k H_1 1500 / d_e$.

4. Calculate the average speed of incidence of particles in a telescopic tube

$$v_s = b_0 + b_1/2 + b_2/6,$$

coefficients are determined by the formulas

$b_0 = n; b_1 = \sqrt{8(1+n^2)} - 3n - 1; b_2 = 4(1 + n - \sqrt{2(1+n^2)})$, $n = v_n / v_k$.

5. The averaged velocities of the ejected air in the telescopic chute (u_s), the speeds of the upward recirculated air in the bypass chamber (ω_s) and the speed of air flowing from the

trough through the openings of the side wall of the chamber (w_s) are expressed through an unknown parameter u_n :

$$u_s = v_s - \sqrt{v_s(\zeta_p u_n^2 - p_y)/\mathrm{Le}}\,,\ w_s = u_n\sqrt{\left(0.25+\zeta_n+\left|0.25-\zeta_k\right|\right)/\left(3\zeta_o\right)}\,,\ \omega_s = \left(u_s - u_n\right)/r\,,$$

where $\zeta_p = \zeta_n + \zeta_k, \zeta_n = \zeta_{nw} + 0.5, \zeta_k = \zeta_{nk} + 1$

6. Functions, parameters, coefficients are introduced through the values obtained at the previous stage.:

$$A = 2\left(u_s - \omega_s / r\right)E/\left(w_s\sqrt{\zeta_0}\right);\ B = \left(1-u_s/v_s\right)\mathrm{Le}\cdot E/\left(w_s\sqrt{\zeta_0}\right);\ k_2 = 2b_2 A/B;\ k_1 = \left(2A(b_1-k_2)-b_2\right)/B;$$

$$a_1 = A+\sqrt{A^2+B}\,;\ a_2 = A-\sqrt{A^2+B}\,; a_3 = n-k_1; b_3 = 1-k_1-k_2; a_4 = b_1-k_2; b_4 = b_1+b_2-k_2; z_1 = e^{a_1}-e^{a_2}\,;$$

$$C_1 = \left(u_n(1-e^{a_2})+a_3e^{a_2}-b_3\right)/z_1;\quad C_2 = \left(u_n(e^{a_1}-1)-a_3e^{a_1}+b_3\right)/z_1$$

and by solving a transcendental equation

$$\left(\zeta_p u_n^2 - p_y\right)E/\left(w_s\sqrt{\zeta_0}\right) - \left(C_1a_1(1-e^{a_1})+C_2a_2(1-e^{a_2})+a_4-b_4\right) = 0$$

determined by the dimensionless velocity of the ejected air at the inlet (and outlet) in the telescopic trough (u_n).

7. The velocity $u(x)$ is calculated (in arbitrary trough sections) on a segment $x = 0\ldots1$: $u(x) = C_1e^{a_1x}+C_2e^{a_2x}+b_0-k_1+x(b_1-k_2)+0.5b_2x^2$ and the mean velocity is determined by integrating the function $u(x)$ on the same segment

$$u_s = C_1(e^{a_1}-1)/a_1 + C_2(e^{a_2}-1)/a_2 + b_0 + (b_1-k_2)/2 + b_2/6 - k_1.$$

8. Cross section x_m is found by olving the equation $C_1a_1e^{a_1x_m}+C_2a_2e^{a_2x_m}+b_1+b_2x_m-k_2=0$ and calculating the maximum value of the dimensionless velocity of the ejected air $u_m = C_1e^{a_1x_m}+C_2e^{a_2x_m}+b_0-k_1+x_m(b_1-k_2)+0.5b_2x_m^2$.

9. The maximum volumetric air flow in the section $x = x_m$ is determined. In the telescopic trough Q_m according to the formula: $Q_m = 3600u_mv_kS_g$, recirculated in the bypass chamber Q_R according to the formula: $Q_R = 3600(u_m-u_n)v_kS_g$ and the difference between these costs $Q_o = Q_m - Q_r$.

10. Calculate the dimensionless overpressure on the bottom of the bypass chamber p_a in accordance with the formula:

$$p_a = 0{,}5\left((\zeta_k-\zeta_n)u_n^2-p_y)\right)+0.5w_s\sqrt{\zeta_o}\left[C_1a_1(1+e^{a_1})+C_2a_2(1+e^{a_2})+a_4+b_4\right]/E\,.$$

11. Calculations of the following dimensionless functions are performed in increments $x = 0{,}1$ (on the interval $x = 0\ldots1$):

$u(x)$ according to the formula: $u = C_1e^{a_1x}+C_2e^{a_2x}+b_0-k_1+x(b_1-k_2)+0.5b_2x^2$,

$p_\omega(x)$ according to the formula: $p_\omega(x) = p_a - 4\omega_s(u(x)-u_n)/r$,

$p(x)$ according to the formula: $p(x) = p_\omega(x) - w_s\sqrt{\zeta_o}\left(C_1a_1e^{a_1x}+C_2a_2e^{a_2x}+b_1-k_2+b_2x\right)/E$,

pressure difference according to the formula: $\Delta p(x) = -p(x) + p_\omega(x)$,

$w(x)$ according to the formula: $w(x) = \Delta p(x) / (\zeta_o w_s)$.

To analyze the changes in the above-mentioned functions, it is convenient to display the values of the argument $x = 0; 0,1; 0,2 \ldots 1$ in the first column, the second value $u(x)$, the third $w(x)$, the fourth $p(x)$, the fifth $p_\omega(x)$ and the sixth $\Delta p(x)$.

12. The dimensionless velocity of the ejected air (u_2) from the equation is calculated:

$$3 / \left(|1-u_2|^3 - |n-u_2|^3 \right) - 2\mathrm{Le}/(\zeta_p u_n^2 - p_y)/(1-n^2) = 0$$

and its consumption $Q_g = 3600 u_n v_k S_g$ m^3 / h for the case of complete sealing of the walls of the trough (that is, in the absence of air recycling in the bypass chamber).

13. The flow rate of air entering from the trough to the aspirated shelter $Q_g = 3600 u_n v_k S_g$, m^3 / h is calculated; the flow rate of air entering the same shelter through leakages $Q_n = 3600 F_a \sqrt{2P_y / (\zeta_m \rho_w)}$ m^3 / h and the required flow rate of air removed from the aspiration shelter $Q_a = Q_g + Q_n$.

12 CONCLUSIONS

- A method of engineering calculation of the volumes of aspirated air during overloads of dry unheated materials with natural circulation has been developed and carried out through the combined use of a cylindrical bypass chamber and a perforated trough. Experimental and numerical studies have shown that the proposed method has sufficient accuracy were performed.
- Recommendations on the design of the aspiration shelter for its more efficient operation with lower operating costs. The economic effect is to reduce energy consumption and the cost of cleaning dust emissions.
- The values of recirculation coefficients for the calculation of the aspiration system when using the bypass chamber and using the combined use of the bypass chamber and trough perforation are proposed.
- A method for calculating the flow rate of ejected air in telescopic loaders has been developed.
- The high energy intensity of telescopic aspiration-technological installations (ATI) of transfer stations is due to the ejection capacity of gravity flows of bulk material, which inject large amounts of air into aspiration shelters, which significantly increases the required performance of aspiration systems. The power of the ATI can be significantly reduced by using coaxially located loading telescopic troughs and corrugated impermeable walls located around the trough, as well as sealing the top and bottom shelters adjacent to the troughs. Coaxially located troughs and bypass chambers contribute to the formation of internal recirculation of the ejected air and a noticeable reduction in the power of transit air coming from the trench to the aspirated shelter.

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